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CONCRETING UNDER TRAFFIC: IN-DEPTH INVESTIGATION OF THE EFFECTS OF VIBRATIONS ON YOUNG CONCRETE

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Abstract

In an ongoing research project, the effects of vibrations on young (reinforced) concrete are being investigated. Such a situation is often encountered at repair and widening works on bridges at the time when parts of newly cast concrete are connected to the existing bridge under running traffic. In the research project, a systematic approach is pursued to investigate the influence of different kinds of vibrations (harmonic, transient/"real"; intermittent, continuous), durations of vibration, concrete mixtures, and construction types (plain concrete, reinforced concrete, direct contact of concrete surfaces). The quality of the shaken test specimens (and respective reference specimens) is determined in terms of strength, density, elastic modulus, cracks, homogeneity, and permeability. Preliminary results indicate that plain concrete does not suffer deteriorations of strength or stiffness when excited by traffic vibrations, in general. However, the bond between concrete and rebar may not evolve properly.

Keywords: Vibrations, Traffic-induced Vibrations, Structural Dynamics, Concrete Hardening, Young Concrete, Multiscale

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1 INTRODUCTION

Regarding vibrations, extensive research has been conducted as far as the effects on both people and (historical) buildings are concerned. On the other side, investigations regarding harmful effects of vibrations on young concrete are very limited [3][4][5][6]. However, transport authorities, construction companies and engineering firms are aware that traffic induced vibrations might afflict permanent damage to concrete structures when the vibrations take place in a certain time range after concrete casting. Regarding this "critical time range", different values can be found in the literature ranging from 3 to 14 hours [8][7][1]. Obviously, this depends on the specific hardening process of the concrete used, which is a function of its composition, the temperature, and other parameters. Therefore, bridges and viaducts often need to be closed for traffic in case that they have direct contact to new components made of concrete, see Figure 1. Such a situation occurs frequently, e.g., when bridges and viaducts are reconstructed, extended, or partially restored.

The aim of the presented (ongoing) project is to investigate the influence of vibrations on young concrete in a very comprehensive and realistic manner. Experiments with plain concrete as well as with reinforced concrete are being performed. Different concrete mixtures are used. Moreover, realistic situations of contact between existing vibrating concrete plates and newly cast concrete parts are studied. A wide range of harmonic vibrations as well as traffic induced vibrations with different intensities and frequencies are being applied. Following the vibration procedure, a variety of material parameters are determined on the test specimens as well as on reference specimens: compression strength, tensile strength, elastic modulus, mass density. Laboratory tests are performed to identify flaws, cracks, and any changes in the concrete texture. The bond between concrete and reinforcement is investigated by means of pull-out tests. Experimental investigations are accompanied by analytical and numerical calculations. Results are verified by finite element analyses, in some cases also adopting multiscale approaches.

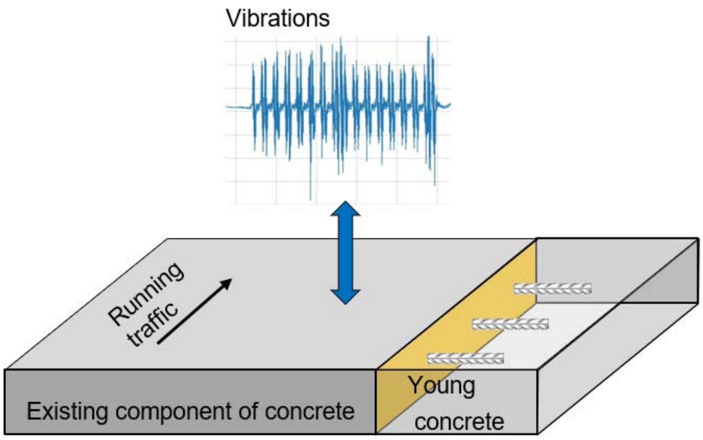

Figure 1: General illustration of the problem: young concrete adjacent to vibrating existent structure

2 TEST PROGRAM

To study the causes and mechanisms of damages, a test program consisting of three series was set up (see Figure 2):

- Series 1: Specimens of plain concrete (in general 150 mm cubes) are excited by a vibration generator, see Figure 3. In this series, the aim is to study the effects of vibrations on the concrete itself. Possible types of damage are especially cracks and segregation of the constituents.

- Series 2: In this series, the test specimens are moulds filled with concrete punched by a rebar through the middle. The test specimens are immobile, while the end of the rebar is excited by the shaker, see Figure 4. This test situation imitates a real situation where a newly cast part is at rest on a scaffold while it is connected to a vibrating existing bridge via rebars. In this series, the effects of vibrations are studied by means of pull-out tests conducted on the 28 days old concrete. Here, the relationship between applied tensile force and slip of the rebar is of interest. Thus, the bond behaviour can be inferred.
- Series 3: This test setup is the one most similar to most real-world problems. A plate of hardened concrete is placed on a platform which is excited by two small shakers. Another plate of young concrete is cast on a stationary pedestal. The two plates are in direct contact to one-another and are furthermore connected via rebars. Figure 5 shows the cross-section of the experimental setup. In this test series, it is expected that the vibrations will impair the bond between the two concrete plates as well as the bond between the rebars and the newly cast concrete. This will be studied by means of bending tests conducted on beams cut out from the shaken concrete slabs.

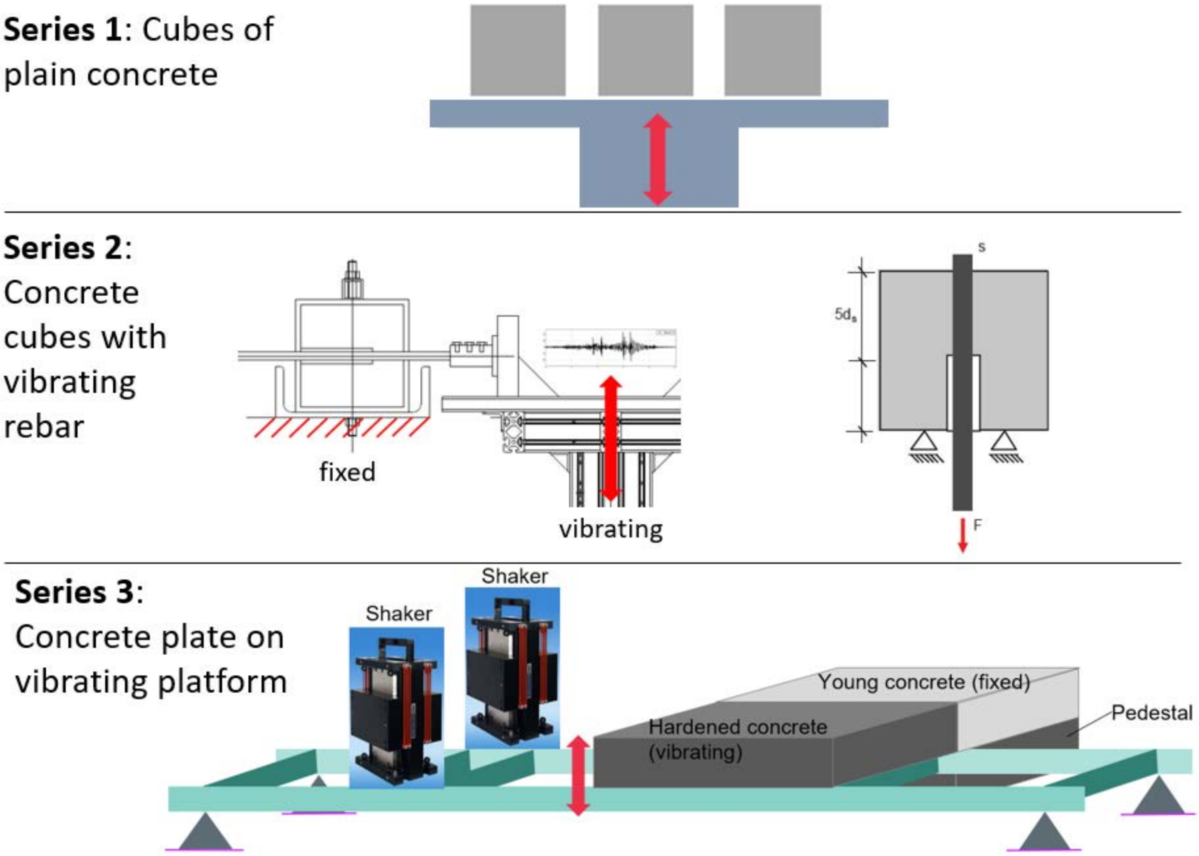

Figure 2: The three series of the test program

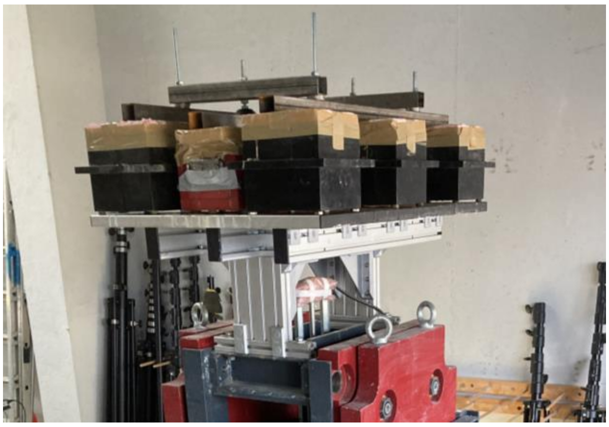

Figure 3: Specimens of plain concrete mounted on vibration generator (Series 1)

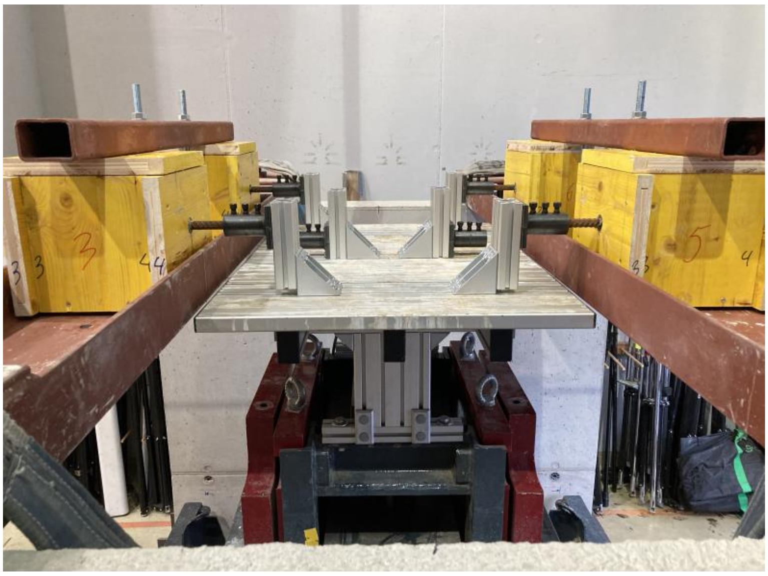

Figure 4: Fixed specimens of concrete with rebar which is subjected to vibrations (Series 2)

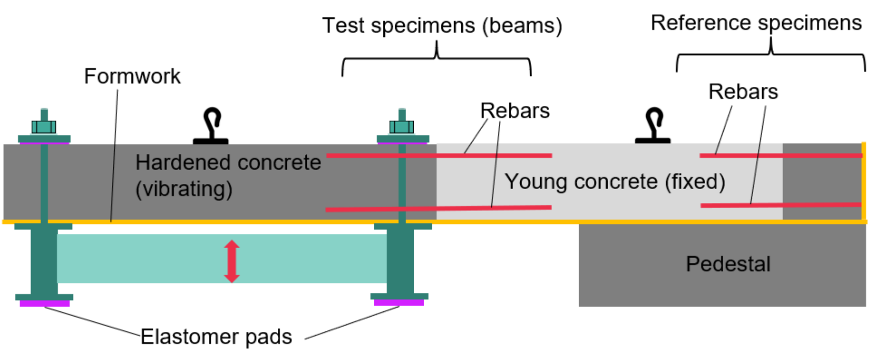

Figure 5: Cross-section of Series 3 setup

A summary of the parameters of the test setup is listed in Table 1. Note that not all the values are combined with all the other values of the parameters. The choice of combinations of parameter values is being done based on realistic situations, expected meaningfulness and outcomes of previous experiments.

Type of excitation	harmonic	5 Hz	Intermittent: excitation of 20 s each 10 min
		20 Hz	
		35 Hz	
	transient	Train	Intermittent: 1 train each 20 min
		Truck	Intermittent: 1 truck each 3 min
		Motorcars	Continuous
Excitation peak velocity		5 mm/s	
		10 mm/s	
		15 mm/s	
		20 mm/s	
		30 mm/s	
		50 mm/s	
		80 mm/s (adopted only exceptionally)	
Duration of excitation		In general: 15 h	
		In some experiments less than 15 h	
Type of concrete	B3	C30/37/F52/GK22 CEM II/B-M (S-L) 42.5 N Cement: 340 kg/m³ Air: 2.5 – 6.5 % Water/cement ratio: 0.55	Note: Typical type of concrete for supporting structure of bridges
	B7	C25/30/F52/GK22 CEM II/A-M (S-L) 42.5 N Cement: 380 kg/m³ Air: 4 – 8 % Water/cement ratio: 0.45	Note: Typical type of concrete used for edge beams (increased frost resistance)

Table 1: Parameters of the test setup

3 EXCITATIONS

Next to harmonic signals, transient signals are being used for the excitations. The transient signals ought to reproduce vibrations of real bridges excited by traffic of trains, trucks, and passenger cars. However, after scrutinizing a great number of recorded signals of bridge vibrations, it became clear to us that the variations of signals, even measured on one and the same bridge, are very large. The reason is that the vibrations are also very much influenced by the traffic. In summary, the intensity, the frequency content, and the duration of the vibration due to passing of a vehicle are influenced by (cf. [7]):

- Natural frequencies of the bridge (primarily by the first one)
- Damping of the bridge
- (Periodic) “disturbances” on the track (e.g., expansion joints)
- Mass of vehicle
- Driving speed
- Distance between axles
- Other factors: Sleeper distance, interaction between wheel and rail/road surface, wheel suspension etc.

Nevertheless, the authors aspired to select sample signals which are somehow typical for the passage of the respective vehicle type over a bridge. Thus, e.g., the passage of the train lasts much longer (19 seconds) than the passage of a truck (2 seconds). Figure 6 shows the train signal, Figure 7 shows the truck signal, and Figure 8 shows the bridge vibrations due to passenger car traffic. Peak velocity is scaled to 20 mm/s for all vehicle types.

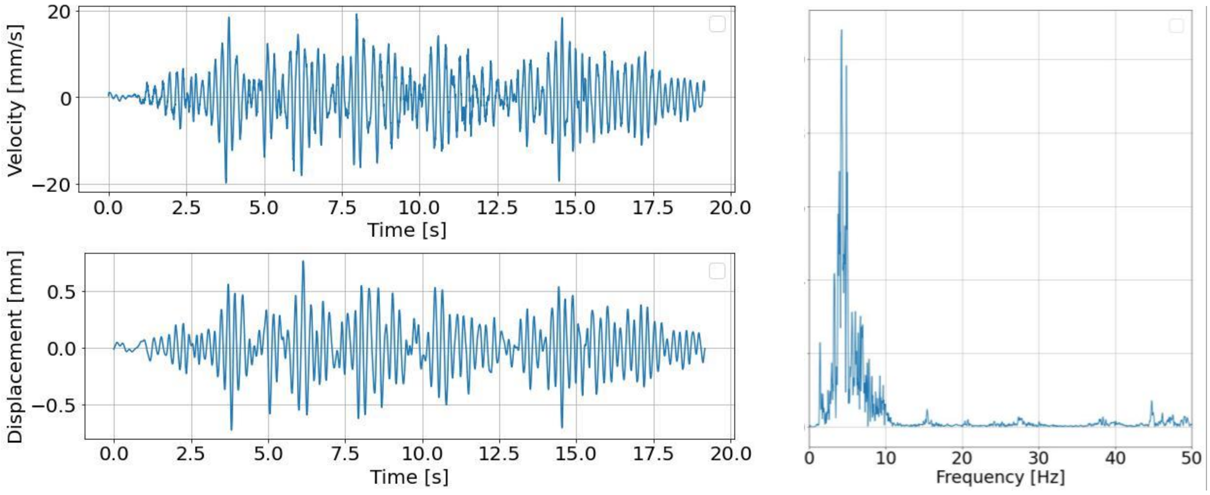

Figure 6: Velocity, displacement, and FFT of velocity caused by passage of (freight) train over a bridge

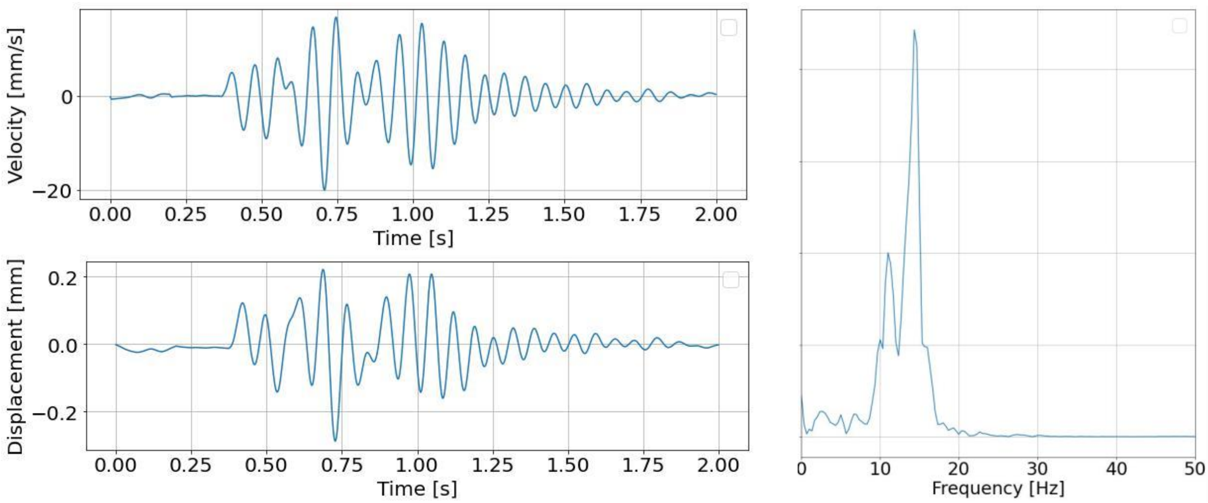

Figure 7: Velocity, displacement, and FFT of velocity caused by passage of truck over a bridge

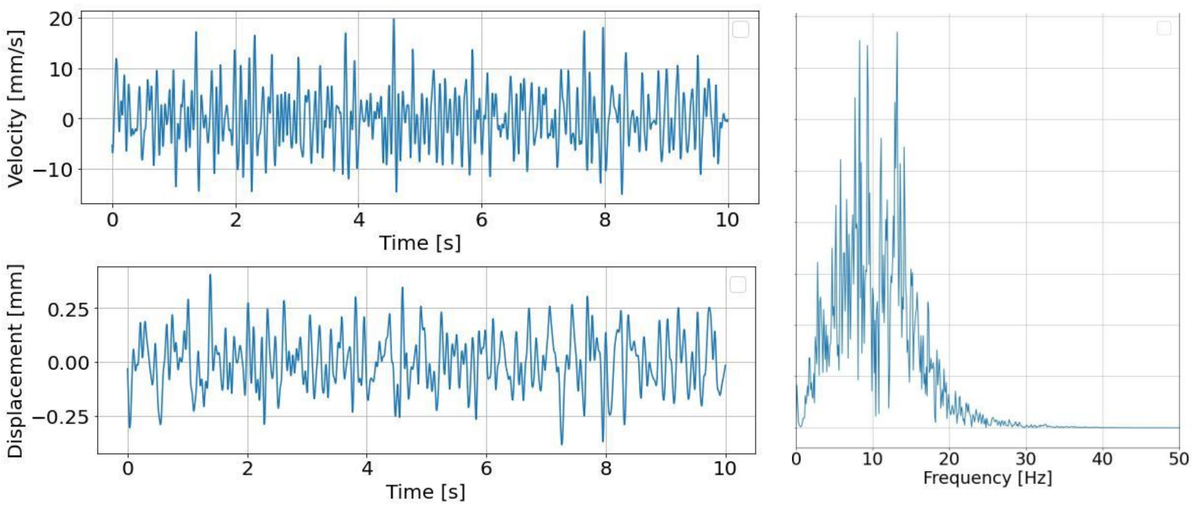

Figure 8: Velocity, displacement, and FFT of velocity caused by passage of passenger cars over a bridge

4 PRELIMINARY RESULTS

4.1 Series 1: Plain concrete

Preliminary lab results indicate that strength and stiffness of plain concrete, in general, are not reduced by vibrations caused by common traffic situations. There is no clear indication that a certain excitation type (a certain frequency) is especially critical. It is even more interesting that also the amplitude of the excitation does not seem to influence the properties of the concrete (the highest excitation amplitude adopted was 80 mm/s).

The following figures show the results in detail. Next to the test results of the specimens excited by harmonic signals (5, 20, and 35 Hz), also the results for traffic of passenger cars (p.c.), trucks, and trains are shown. The type of concrete is “B3”, cf. Table 1. If available, also the mean values of respective reference results (of specimens at rest) are indicated (m.v.ref.).

The most noticeable result is that, for some test cases, the elastic modulus is considerable (ca. 35%) lower than the elastic modulus of most other specimens (which is usually around 42,000 MPa). However, the lowest values of the elastic modulus are observed for the middle frequency (10 Hz) and for the lower excitation amplitudes, and additionally for the passenger car excitation. From a rational point of view this behaviour is difficult to explain. Unfortunately, a reference elastic modulus is not available for each single experiment.

Hence, the elastic modulus of these “suspicious specimens” was additionally determined by dynamic testing (ultra-sonic). Interestingly, using this method, the elastic modulus of these specimens is equally high as the one of the other specimens. Further tests will provide more insight into these observations.

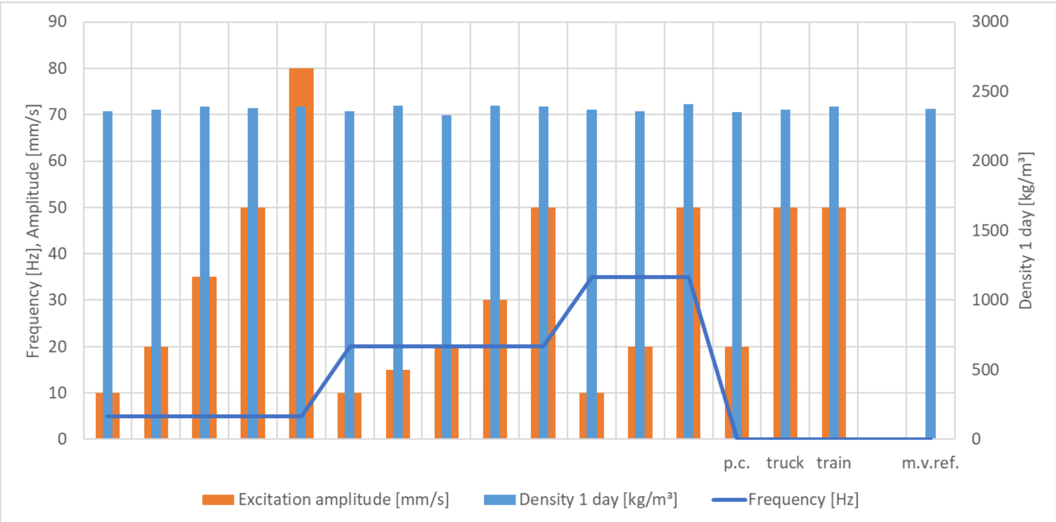

Figure 9: Density after 1 day

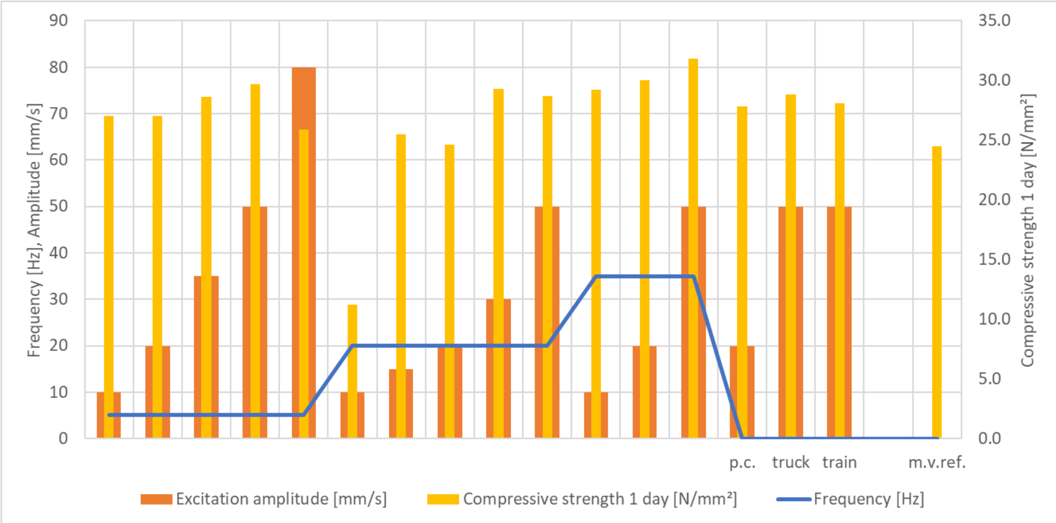

Figure 10: Compressive strength after 1 day

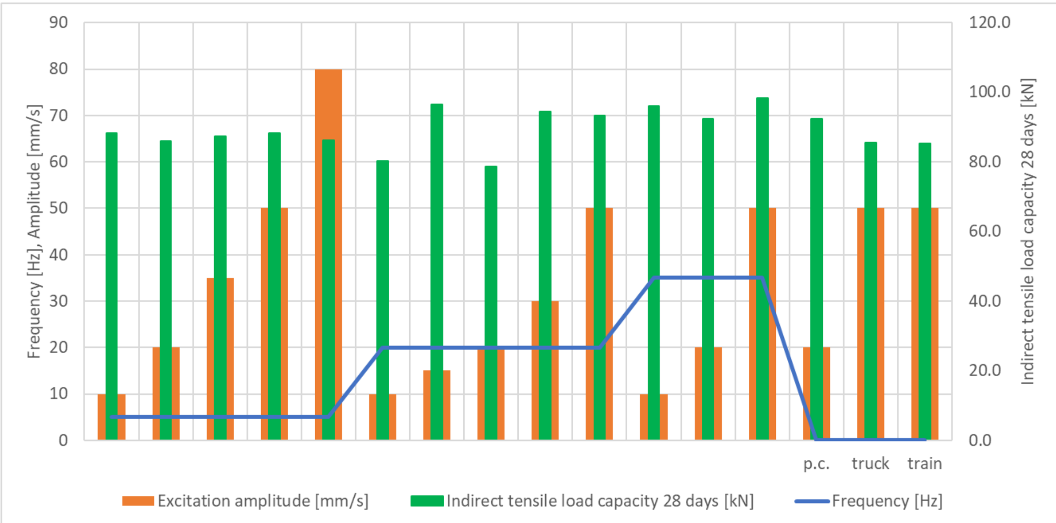

Figure 11: Indirect tensile load capacity after 28 days

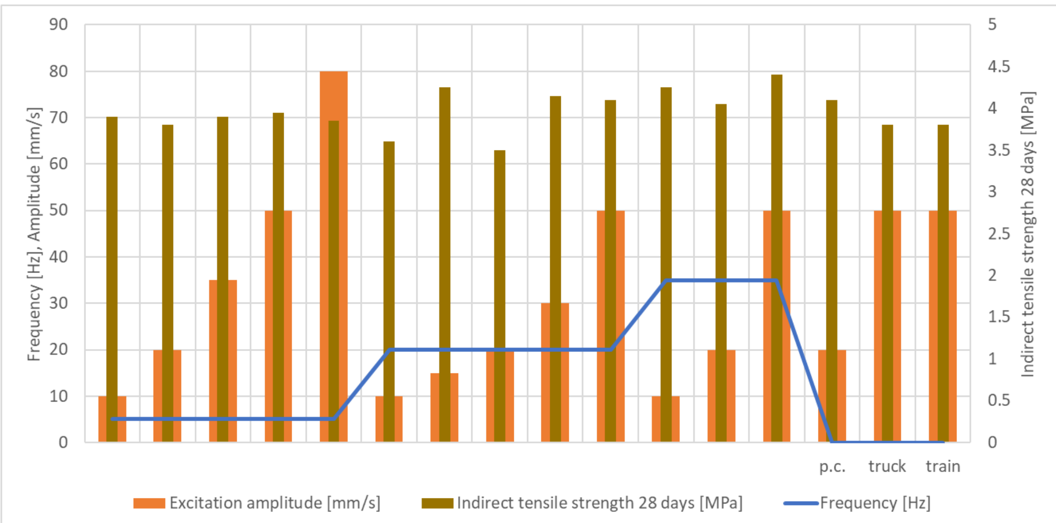

Figure 12: Indirect tensile strength after 28 days

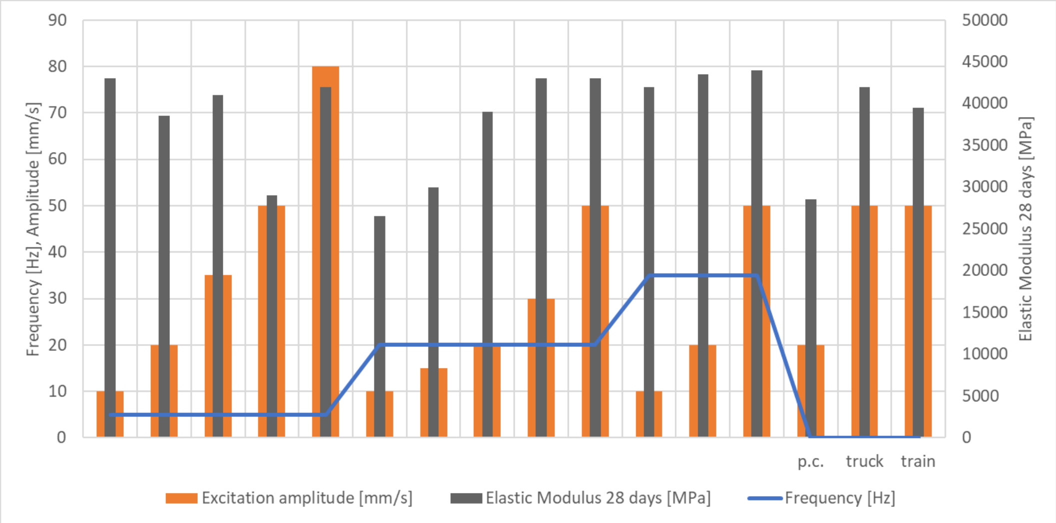

Figure 13: Elastic Modulus after 28 days

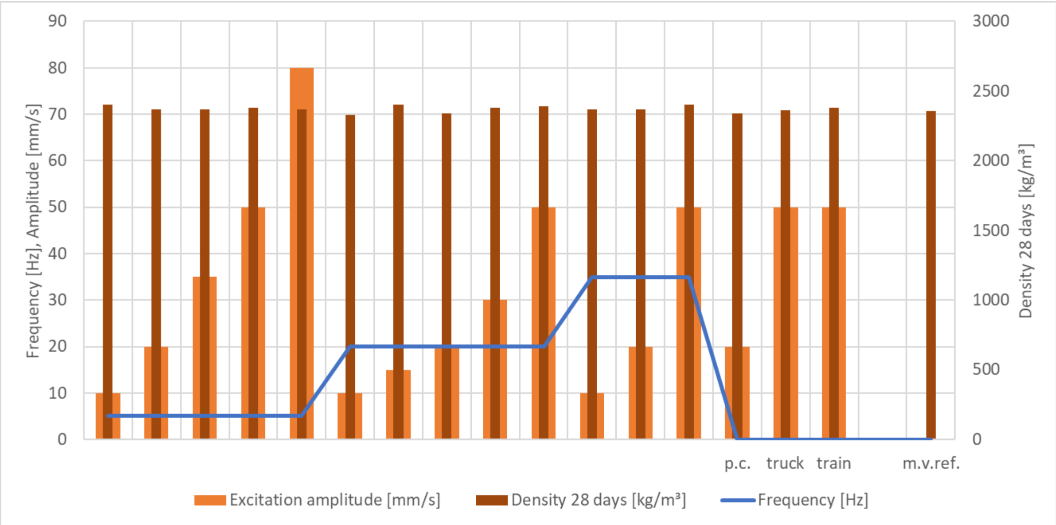

Figure 14: Density after 28 days

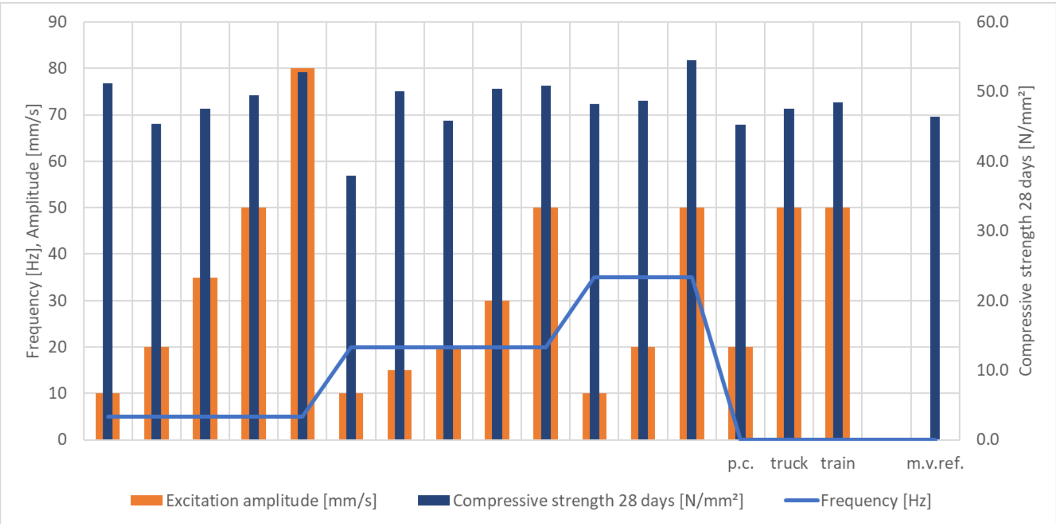

Figure 15: Compressive strength after 28 days

Multiscale Modelling

The specimens of plain concrete are being further tested for variations in porosity and microstructure. By means of a micro-X-ray fluorescence analysis, it was found that some shaken specimens exhibit a microstructure where the (larger) aggregates tend to accumulate rather in the lower area of the specimen while there is a higher concentration of cement in the upper part (compared to the reference specimens).
To see the expected macroscopic effects of such microscopic variations, a multiscale analysis was performed. The aim is to capture the behaviour of concrete at a macroscopic scale by accounting for the complex interactions between the different constituent phases at a microscopic level by averaging them. Hence, Representative Volume Elements (RVEs) are generated for both the reference sample and the vibrated sample, which differ slightly in terms of the distribution of aggregates, see Figure 16.

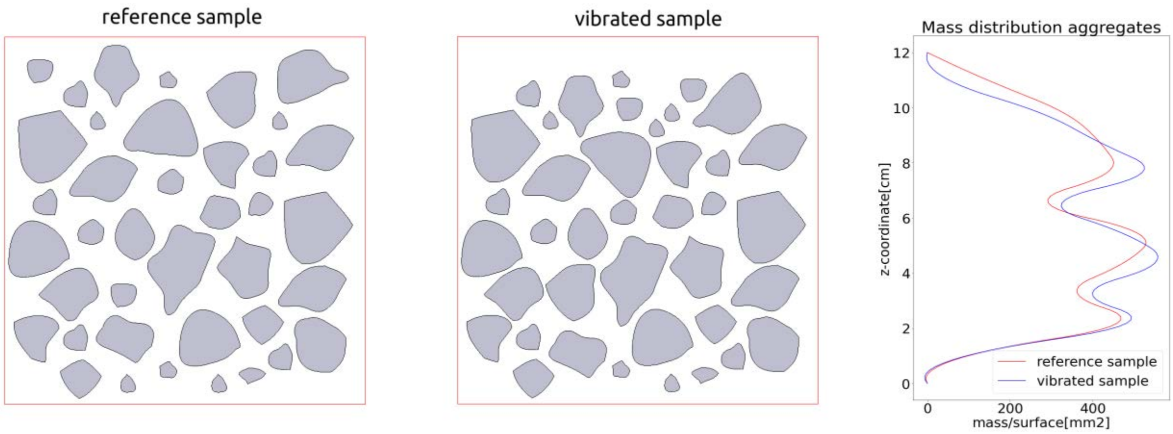

Figure 16: Representative volume element (RVE) used in the multiscale analysis: Left: reference sample (homogeneous distribution of aggregates), middle: vibrated sample (tendency of aggregates to accumulate in the lower part), right: distributions of aggregates over the hight of the sample.

In the analysis, cement is assigned an elastic modulus of 30,000 N/mm² and the aggregates are assigned an elastic modulus of 50,000 N/mm². For the homogenization method, periodic boundary conditions are used.
The resulting elastic moduli for the concrete are 34,460 N/mm² for the reference sample and 34,360 N/mm² for the sample exposed to vibrations, respectively. Thus, the difference is only 0.3%. This small demonstrative example shows that small rearrangements of the components that can occur due to vibrations do not alter the elastic properties of the concrete specimens significantly. This finding is in full congruence with the macroscopic test results presented previously.

4.2 Serie 2: Pull-out Tests

So far, only the results of the samples excited by train passage signals are available. The quality of the concrete-rebar bond was studied by means of pull-out tests [9]. The results are shown in Figure 17 in terms of the mean value of the maximum force reached in the pull-out test. The samples excited by a train passage signal with peak value equal to 10 mm/s reached a peak pull-out force of approximately 70 kN, which is in the range of fluctuation of the reference values (mean value 75 kN). However, the bond of the samples excited with a maximum of 20 mm/s is clearly damaged since the (mean) peak pull-out force is nearly 40% lower than for the reference samples. In the case of 50 mm/s, the peak pull-out force is again much reduced (minus 73% compared to reference).

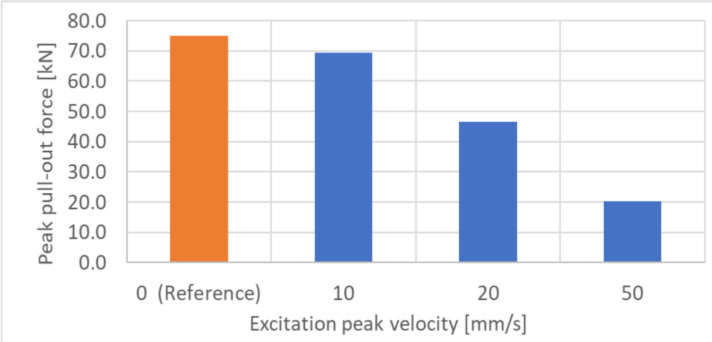

Figure 17: Peak pull-out forces performed with reinforced concrete samples excited by train passage signals

5 CONCLUSIONS

Preliminary lab results indicate that strength and stiffness of plain concrete, in general, are not reduced by vibrations caused by common traffic situations. However, latest results show very clearly that the bond between concrete and rebars may be damaged by strong vibrations.

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